INCLUSIVE ϕ -MESON PRODUCTION IN 93 AND 63 GEV HADRON INTERACTION

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AbstractThe inclusive reactions

$$h + p \rightarrow \phi + X \quad (h = \pi^{\pm}, K^{\pm}, p^{\pm})$$

are studied for $0 \leq x_F \leq 0.3$ and $p_{\perp} < 1$ GeV at 93 and 63 GeV incident momentum. Differential cross sections $d\sigma/dp_{\perp}^2$ and $d\sigma/dx_F$ are presented and are compared with predictions of the naive parton model.

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I. Introduction

In an experiment with the WA 3 spectrometer in the West-Area of the CERN-SPS, inclusive ϕ -meson production off protons has been studied for incident $\pi^{+/-}$, $K^{+/-}$, $p^{+/-}$ at 93 GeV and π^- , K^- , $\bar{p}$ at 63 GeV incident momentum.^{1,2} The range of Feynman x_F ($x_F = 2p_{\parallel}/\sqrt{s}$) covered by the experiment is $.04 < x_F < .24$ for the 93 GeV data and $.12 < x_F < .36$ for the 63 GeV data. The transverse momentum is limited to $p_{\perp} \lesssim 1$ GeV.

Experimental data on the inclusive production of ϕ -mesons in hadron interactions are relatively scarce. This is somewhat surprising since the ϕ -meson is the first member of the series of hidden flavour vector mesons and a systematic study of its production characteristics might be useful in understanding the production dynamics of the heavier onia. Particularly interesting is the fact that the ϕ -meson can be produced by K-mesons, i.e. a particle which contains the hidden quark as the valence quark, something which is not possible for the J/Ψ and the T. Moreover, experimental conditions for studying ϕ -meson production are quite favourable. The inclusive cross section is large (of the order of 100 μb), while the $\phi \rightarrow K^+K^-$ decay (branching ratio of .486), provides a good signature; a narrow width peak just above threshold in the K^+K^- invariant mass spectrum. Another interesting feature is the possibility to measure rather easily the possible associated production of strange particles, something which can be done only indirectly for J/Ψ production.

In a previous paper we have studied strange particle production in conjunction with the ϕ -meson²⁾. In this paper we will concentrate on a study of the differential cross sections $d\sigma/dp_{\perp}^2$ and $d\sigma/dx_F$. Data will be presented for incident π^+ , p^+ and K^+ . The results will be compared with predictions of a simple parton model. It is basically the quark fusion model proposed by Donnachie and Landshoff^{3,4,5)}, including an additional term to account for a possible gluon fusion contribution. The quark fusion model provides a good description of both J/Ψ and T production in hadron collisions. It also describes successfully inclusive ϕ production in photon interactions⁶⁾. The slightly extended model used in our analysis is also in good agreement with our data. The contribution of the fusion of strange quarks to the inclusive ϕ cross section is found to be large. The same conclusion was reached in the study of associated strange particle production²⁾. It supports the basic assumptions put forward in references [3-6].

II. Experiment and data

In previous papers ^{1,2}) we have described the apparatus and the trigger for our inclusive ϕ -experiment. The ϕ -meson was observed through its K^+K^- decay mode. A Cerenkov hodoscope was used to identify charged K-mesons. In order to be labelled as a K-meson, a particle was required to pass a cell of this Cerenkov counter without giving light. In the subsequent analysis a further restriction was imposed by demanding that the momentum of these particles was contained in the interval $3.7 < p_K < 13$ GeV, the limits corresponding to the π^- and K-threshold respectively of the Cerenkov counter. Our sample of K^+K^- pairs accordingly will include a background of events in which the K^+ is a proton and/or the K^- an anti-proton.

This momentum selection determines the range of x_F to which our experiment is sensitive. Since the threshold setting is the same for the 93 GeV and the 63 GeV data, the region of x_F is shifted to slightly higher values for the 63 GeV data. In Fig 1 we show in the $x_F, p_\perp$ plane, lines of equal acceptance for the 93 GeV and the 63 GeV data respectively. The acceptance is calculated assuming an isotropic decay angular distribution of the ϕ -meson. All sources of event loss which depend on the kinematic variables of the reaction are taken into account; i.e. the momentum cut, the geometric acceptance of the apparatus, the decay probability of the K-mesons and the conditions imposed on the events by the hardware trigger (including the trigger loss due to fast pions passing the same Cerenkov cell as the K-meson) and by the software selection. Other losses are combined into an overall scale factor by which the nb equivalent of the experiment has been multiplied.

The total number of triggers recorded, as well as the observed number of ϕ events and the nb equivalent for one observed event (corrected for unseen decay modes of the ϕ) for the different data subsets are listed in Table 1. The corresponding K^+K^- invariant mass spectra in the mass range $.98 < m_{K^+K^-} < 1.05$ GeV are shown in fig. 2. The curves in fig. 2 represent the best fits obtained using a Breit-Wigner for the ϕ -meson superimposed on a polynomial background. The Breit-Wigner has a fixed width $\Gamma_\phi = 4.1$ MeV and is folded with the mass resolution. The central mass value ($1019.6 \pm .1$ MeV) and the mass resolution (1.4 MeV) have been determined from the 93 GeV incident π^- data. The systematic error in the ϕ -mass is smaller than .1 MeV, using samples of K_S^0 and Λ decays observed in the same experiment for calibration.

The signal to background ratio at the ϕ -mass is about one. The background consists partly of non-resonating K^+K^- pairs ($\sim 40\%$) but also includes $K\rho$

and $\bar{p}p$ pairs since K-mesons and protons cannot be distinguished below the K-threshold of the Cerenkov counter. Moreover, some $K\pi$ combinations enter due to misidentified pions. When calculating differential cross sections, the background under the ϕ -peak is estimated from the adjacent mass bins, assuming that there is no rapid variation of the kinematic properties over this relatively small mass range. After background subtraction the ϕ -signal has been corrected, as a function of x_F and $p_{\perp}$, for the acceptance losses mentioned before. Here the non-trivial assumption is made that the decay angular distribution is isotropic. Although this has not been rigorously proven for the full x_F , $p_{\perp}$ range studied in this experiment, the isotropy of $\cos\theta_{GJ}$ and ϕ_{GJ} , the decay angles in the Gottfried Jackson frame, has been demonstrated in the $x_F, p_{\perp}$ range indicated in fig. 1. In this area there are no zero acceptance regions in the $\cos\theta_{GJ}$, ϕ_{GJ} plane so that acceptance corrections can be made for each individual observed event by rotating the event around the beam axis and testing whether the rotated event satisfies the acceptance criteria. In fig. 3. we show for this particular class of events the $\cos\theta_{GJ}$ and ϕ_{GJ} distributions. They are consistent with isotropy.

The differential cross sections $d\sigma/dp_{\perp}^2$ and $d\sigma/dx_F$ for the different data samples are shown in figs. 4. and 5. The error bars represent statistical errors only. An overall scale error of about 10% due to the uncertainty in calculating the nb equivalent has to be applied when comparing the -93, +93 and -63 GeV data. Within each of these groups an additional systematic error of $\sim 5\%$ accounts for uncertainties in the relative incident beam rates. The $p_{\perp}^2$ distributions are obtained by integrating over the x_F -interval $.1 < x_F < .2$ and $.15 < x_F < .25$ for the 93 GeV and 63 GeV data respectively. The result of a fit to the distributions with an exponential $e^{-\alpha p_{\perp}^2}$ is indicated in fig. 4., the slope values are listed in Table 2, together with the slope values β for a fit with an exponential function $e^{-\beta p_{\perp}}$. Within the experimental errors the values of α are consistent ($\alpha \approx 3$) independent of energy and beam particle. The agreement with other experiments is fair⁶⁻¹⁵).

The values of $d\sigma/dx_F$ refer to the full $p_{\perp}$ range. For this the integrated data in the interval $0. < p_{\perp} < .8$ GeV are used, assuming a distribution $e^{-3p_{\perp}^2}$ to extrapolate to values $p_{\perp} > 0.8$ GeV. The values of the cross sections integrated over the range $.04 < x_F < .24$ and $.12 < x_F < .36$ for 93 GeV and 63 GeV data respectively are listed in Table 3*.

The cross sections for incident $K^{\pm}$ are systematically higher than for incident $\pi^{\pm}$ and p, in agreement with observations from other experiments¹²). The

* The values of σ_{tot} are estimates of the total ϕ -production cross section from the model fits described in section III.

statistical significance of the 63 GeV incident $\bar{p}$ data is extremely poor; the cross section for this sample is given only for completeness.

III Interpretation of results

We have tried to interpret our results in terms of a parton model taking into account contributions of the processes indicated in the diagrams of fig. 6. Although the use of the parton model may be questionable in view of the low mass of the ϕ -meson, it is tempting, given the simplicity of the model, to see whether it can provide an acceptable description of the production characteristics of inclusive ϕ -production.

In a previous paper ²⁾ we have demonstrated that enhanced production of strange particles occurs in reactions where a ϕ -meson is present in the final state. This is expected for reactions which proceed through the Okubo-Zweig-Iizuka (OZI) allowed fusion of strange quarks (fig. 6a). From the measured excess of strange particles it was concluded that this process accounts for at least 30-40% of the inclusive ϕ cross section. Additional support for the assumption that strange quark fusion plays an important role, comes from the observation that the cross section is significantly larger when the incident particle is a K-meson. These two results suggest that ϕ production is not dominated by gluon fusion (fig 6c) as has been suggested elsewhere¹⁶⁾. The results of Table 3 also indicate that the OZI inhibited fusion of light quarks (fig 6b) gives a small contribution, otherwise the cross section for incident $\bar{p}$ should be significantly larger than that for incident p or π , in contrast with the data.

In the following we will try to describe our results in a more quantitative way. For this the differential cross sections $d\sigma/dx_F$ are written as a sum of three terms,^{4,5)} corresponding with the three diagrams shown in fig. 6, i.e.

$$\begin{aligned} \frac{d\sigma}{dx_F} = & \frac{\sqrt{s}}{2E} \cdot \frac{4\pi^2}{3m_\phi^2} \left[\frac{g_A^2}{4\pi} \left\{ F_a^s(x_1) F_p^{\bar{s}}(x_2) + F_a^{\bar{s}}(x_1) F_p^s(x_2) \right\} + \right. \\ & \frac{g_I^2}{4\pi} \sum_{\alpha=u,d} \left\{ F_a^\alpha(x_1) F_p^{\bar{\alpha}}(x_2) + F_a^{\bar{\alpha}}(x_1) F_p^\alpha(x_2) \right\} + \\ & \left. \frac{g_G^2}{4\pi} G_a(x_1) G_p(x_2) \right] \quad (1) \end{aligned}$$

where $g_A^2/4\pi$ and $g_I^2/4\pi$ are the coupling constants for the OZI allowed and inhibited fusion of strange and light quarks respectively and $g_G^2/4\pi$ is the effective gluon coupling constant representing the gluon fusion diagram of fig. 6c. $F_{a,p}^{\alpha,s}$ ($\bar{F}_{a,p}^{\bar{\alpha},\bar{s}}$) are the quark (anti-quark) distribution functions of particle a and target proton respectively. G_a and G_p are similarly the gluon distribution functions. The fractional longitudinal momenta of the partons, x_1 and x_2 , are obtained from the relations

$$x_F = x_1 - x_2, \text{ and}$$

$$x_1 x_2 s = m^2 \phi - 2m_q^2 \quad (2)$$

where m_q , the parton mass, is taken to be non zero only for the s-quark i.e. $m_s = .5$ GeV. To evaluate expression (1) numerically for incident π , K and p the following set of distribution functions for valence quarks (V), sea quarks (S) and gluons (G) have been used.

$$V_p^u(x) = 1.09 x^{1/2} (1-x)^3 \quad (3a)$$

$$V_p^d(x) = 1.23 x^{1/2} (1-x)^4 \quad (3b)$$

$$V_{\pi}^{u,d}(x) = .55 x^{.4} (1-x)^{.9} \quad (3c)$$

$$V_K^{u,d}(x) = .60 x^{.4} (1-x)^{1.3} \quad (3d)$$

$$V_K^s(x) = 1.38 x^{.8} (1-x)^{.9} \quad (3e)$$

$$S_p^{u,d,s}(x) = .17 (1-x)^6 \quad (3f)$$

$$S_{\pi,K}^{u,d,s}(x) = .09 (1-x)^{4.4} \quad (3g)$$

$$G_p(x) = 2.5 (1-x)^4 \quad (3h)$$

$$G_{\pi}(x) = G_K(x) = 2 (1-x)^3 \quad (3i)$$

The light quark distributions of p and π are those of reference [17, 18]. For the strange quarks we have assumed that both proton and pions have an SU(3) symmetric sea. This does not agree with recent results of the CDHS group¹⁹⁾, which indicate that the strange sea is suppressed relative to the light quark sea by a factor of about .5. However, there is a large uncertainty in the absolute normalization of the sea quark distributions and hence a possible suppression of the strange quarks can be easily absorbed in the overall normalization factor. The valence quark distributions of the K-meson have been determined using the prescriptions of Chliapnikov²⁰⁾. The u-quark distribution is in good agreement with the result of reference [21].

The gluon distributions are those suggested by the counting rules. There is a recent measurement of the gluon distribution in the proton ²²). However, the errors in $G(x)$ are quite large and the choice of the distribution functions is quite arbitrary given the uncertainty due to the transition of the $C=+1$ $s\bar{s}$ state into the $C=-1$ ϕ -meson.

We will use the integrated data in column 4 of Table 3 to estimate the relative contributions of the three terms in expression (1). Then the shape of the $d\sigma/dx_F$ distribution can be determined and compared with the data.

From Table 3 it follows that

$$\begin{aligned} (\sigma_{K^-p} - \sigma_{\pi^-p})_{93 \text{ GeV}} &= 36.5 \pm 6.5 \text{ } \mu\text{b} \\ (\sigma_{K^+p} - \sigma_{\pi^+p})_{93 \text{ GeV}} &= 33.1 \pm 15.7 \text{ } \mu\text{b} \end{aligned} \quad (4)$$

In the quark fusion model these differences are almost exclusively due to the contribution of the s-valence quark in the K-meson. Allowing for a small effect from light quark fusion diagrams, which are slightly different for π and K interactions, we estimate this contribution to be approximately 40 μb . Equating this to the value obtained from expression (1), using the distribution functions (3) and integrating over the x_F interval $.04 < x_F < .24$ leads to

$$\frac{g^2}{4\pi} = .23$$

which is of the right order of magnitude assuming the coupling of ϕ to $s\bar{s}$ to be much the same as the coupling of ρ to $u\bar{u}$, $d\bar{d}$, i.e. $\frac{g^2}{4\pi} \approx .5$.

The differences between the cross sections for pp and $\bar{p}p$, π^-p and π^+p , K^-p and K^+p interactions have to be attributed to OZI inhibited light quark fusion diagrams, in particular those involving a valence quark. The measured differences at 93GeV are

$$\begin{aligned} \sigma_{\bar{p}p} - \sigma_{pp} &= 14.6 \pm 25 \text{ } \mu\text{b} \\ \sigma_{\pi^-p} - \sigma_{\pi^+p} &= 0.2 \pm 8 \text{ } \mu\text{b} \\ \sigma_{K^-p} - \sigma_{K^+p} &= 3.6 \pm 15 \text{ } \mu\text{b} \end{aligned} \quad (5) ,$$

where the errors do not include a possible systematic scale error of about 10 μb . These differences are used to estimate the OZI inhibited coupling constant. Evaluating expression (1) we obtain from (5) the following three

values for $g_I^2/4\pi$

$$g_I^2/4\pi = .01 \pm .02$$

$$g_I^2/4\pi = .00 \pm .05$$

$$g_I^2/4\pi = .01 \pm .04$$

Another estimate follows from the observed excess of strange particles in conjunction with ϕ -meson production²⁾. This indicates that not more than 65% of the cross section in π^-p interactions can be accounted for by gluon or light quark fusion. From this it follows that

$$g_I^2/4\pi < .05$$

From a comparison of the cross sections for ω and ϕ production^{8,23,27)} and the ratio $\Gamma(\phi \rightarrow 3\pi)/\Gamma(\omega \rightarrow 3\pi)$ the value of the Zweig violating coupling $g_I^2/4\pi$ can be estimated to be less than about 0.03 in good agreement with the values given above.

Finally we come to the contribution of the Zweig allowed fusion of strange sea quarks. Our excess of strange particles²⁾ indicates for π^-p interactions a cross section from this source of 20 - 25 μb . The cross section, calculated from expressions (1) and (2) and the value $g_A^2/4\pi = 0.23$ derived before, is 14 μb . The small difference between measured and expected predicted cross sections can be easily accommodated by changing - remaining within the quoted errors¹⁸⁾ - the normalization of the sea quark distribution function in the pion.

Given the relatively large errors in the cross sections in Table 3 the best choice for the various parameters in (1) is slightly arbitrary, in particular with respect to the relative contribution of gluon fusion and light quark fusion. A good representation of the 93 GeV data is obtained with the following values

$$g_A^2/4\pi = .23$$

$$g_I^2/4\pi = .01$$

$$g_G^2/4\pi = .0025,$$

increasing at the same time the normalization constant of $S_{\pi,K}^{u,d,s}$ in (3g) by a factor 1.5. The resulting differential cross sections $d\sigma/dx_F$ are shown in fig. 5. The predicted shapes agree with the data. In particular they account

well for the observed differences in the slope of π^-p , K^-p and pp distributions, where the statistics is sufficiently large to allow such a comparison. When applying the same procedure to the 63 GeV data the calculated integrated cross sections for π^-p , $\bar{p}p$, and Kp are 38 μb , 38 μb and 82 μb respectively. When comparing these values with the measured ones (Table 3, column 4) they indicate a possible scale error of the order of 25%. The normalized distributions are shown in fig. 5 g,h,i. Again the π^-p distribution shows good agreement with the data.

Assuming that the $d\sigma/dx_F$ distributions over the full x_F range are well represented by equation (1), an estimate of the total inclusive cross section for ϕ -meson production can be made. We obtain with the parametrization described before and normalizing to the measured cross section in the appropriate x_F -interval, the total cross section values listed in Table 3. Apart from the indicated statistical error and the previously mentioned scale error of 10-15%, an additional uncertainty is introduced by our extrapolation outside the measured x_F -range. Since our measurements are made at small x_F , we believe this systematic error for the πp and pp interactions, where the ϕ is centrally produced, to be smaller than 20%. For incident K-mesons a strong beam fragmentation component has been observed ^{11,12)}, suggesting important contributions from other processes than the ones shown in fig. 6. Accordingly the total cross sections for incident K-mesons have a larger uncertainty; and are presumably underestimated.

IV Conclusions

Our measurements of inclusive ϕ -meson production at small x_F appear to be in good agreement with expectations from the naive parton model. In particular they support the conclusion made in a previous paper ²⁾ - based on the observation in the same experiment of an excess of strange particles produced in association with the ϕ -, that strange quark fusion accounts for a large fraction of the inclusive ϕ cross section. Under the assumption that the cross section in the measured x_F -range comes indeed from the parton diagrams of fig. 6, we obtain estimates for the coupling constants of the OZI allowed and OZI inhibited processes that are in good agreement with the expected values. Also the shapes of the differential cross sections $d\sigma/dx_F$ are well represented by the parton model predictions at least in those reactions where we have good statistics. We therefore conclude that despite the low mass of the ϕ -mesons the naive parton model provides a successful framework

for the description of inclusive ϕ -meson production. It would be of great interest to have high statistics data in a wider x-interval over a large range of $\sqrt{s}$ to check the predictions of the model in more detail.

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REFERENCES

- 1) C. Daum et al., Phys. Lett. 90B (1980) 475
- 2) C. Daum et al., CERN preprint CERN-EP/80-184
- 3) A. Donnachie and P.V. Landshoff, Nucl. Phys. B112 (1976) 233
- 4) R. Moore and A. Donnachie, J. Phys. G 4 (1978) 1835
- 5) A. Donnachie and P.V. Landshoff, Z. Phys. C 4 (1980) 231
- 6) D. Aston et al., CERN preprint CERN-EP/80-181
- 7) B. Ghidini et al., Nucl. Phys.
- 8) V. Blobel et al., Phys. Lett. 59B (1975) 88
- 9) C. Louedec et al., Nuovo Cim. 41A (1977) 166
- 10) P. Granet et al., Nucl. Phys. B 140 (1978) 389
- 11) C. Cochet et al., Nucl. Phys. B 155 (1979) 333
- 12) Aachen-Berlin-Bonn-CERN-Cracow-Heidelberg-Innsbruck-London-Vienna-Warsaw
Collaboration, submitted to EPS conference, Geneva (1979)
- 13) K.J. Anderson et al., Phys. Rev. Lett. 37 (1976) 799
- 14) C.W. Akerlof et al., Phys. Rev. Lett. 39 (1979) 861
- 15) J. Badier et al., CERN preprint, CERN/EP 79-61
- 16) R. Kinnunen, University of Helsinki report, HU-P-185
- 17) J.G.H. de Groot et al., Z. Phys. C1 (1979) 143
- 18) J. Badier et al., CERN preprint, CERN/EP 79-67
- 19) J. Knobloch, paper presented at the XXth International Conference on High
Energy Physics, Madison 1980
- 20) P.V. Chliapnikov et al., Nucl. Phys. B 148 (1979) 400
- 21) J. Badier et al., Phys. Lett. 93B (1980) 354
- 22) J. Lefrancois, Rapporteurs Talk XXth International Conference on High Energy
Physics, Madison 1980
- 23) R.A. Donald et al., Phys. Lett. 61B (1976) 210
- 24) P.L. Woodworth et al., Phys. Lett. 65B (1976) 89
- 25) R. Baldi et al., Phys. Lett. 65B (1977) 381
- 26) Cohen et al., Phys. Rev. Lett. 38 (1977) 269
- 27) B. Ghidini et al., Phys. Lett. 68B (1977) 186

TABLE 1

Beam	Total number of triggers	Incident particle	Number of ϕ mesons	nb equivalent
-93 GeV	800,000	π	5558	3.6 ± 0.3
		K	1403	23.8 ± 1.9
		$\bar{p}$	169	115.2 ± 9.2
-63 GeV	250,000	π	1925	11.5 ± 0.6
		K	692	82.0 ± 4.7
		$\bar{p}$	80	217 ± 14
+93 GeV	300,000	π	438	41.5 ± 3.2
		K	285	115.0 ± 9.2
		p	1272	18.2 ± 1.5

TABLE 2

Momentum x-range $p_{\perp}$ -range	93 .1 < x < .2 0. < p_T < .8		63 .15 < x < .25 0. < $p_{\perp}$ < .8	
	α	β	α	β
$\pi^- p$	$3.23 \pm .23$	$2.58 \pm .17$	$2.77 \pm .51$	$2.07 \pm .35$
$\pi^+ p$	3.22 ± 1.04	$2.47 \pm .71$		
$K^- p$	$2.75 \pm .40$	$2.15 \pm .29$	$4.28 \pm .81$	$3.19 \pm .48$
$K^+ p$	$2.52 \pm .76$	$1.99 \pm .58$		
$\bar{p} p$	3.69 ± 1.78	3.23 ± 1.15	3.91 ± 3.39	3.09 ± 2.18
p p	$3.34 \pm .57$	$2.49 \pm .38$		

TABLE 3

Beam momentum [GeV]	$x_F^L < x_F < x_F^U$	Incident particle	$\int_{x_F^L}^{x_F^U} \frac{d\sigma}{dx_F} dx_F [\mu b]$	$\sigma_{tot} [\mu b]$
93	.04 < x < .24	π^+	61.3 $\pm$ 7.7	178 $\pm$ 22
		π^-	61.5 $\pm$ 2.6	180 $\pm$ 8
		K^+	94.4 $\pm$ 13.7	296 $\pm$ 43
		K^-	98. $\pm$ 6	309 $\pm$ 19
		p	72.4 $\pm$ 7.1	221 $\pm$ 22
		$\bar{p}$	87.0 $\pm$ 24	268 $\pm$ 74
63	.12 < x_F < .36	π^-	52.4 $\pm$ 2.9	205 $\pm$ 11
		K^-	111 $\pm$ 10	373 $\pm$ 34
		$\bar{p}$	24 $\pm$ 10	113 $\pm$ 47

FIGURE CAPTIONS

Fig. 1 Lines of constant acceptance (%) for inclusive ϕ -production as a function of x_F and $p_{\perp}$; (a) 63 GeV (b) 93 GeV incident momentum. The dashed contour indicates the $x_F, p_{\perp}$ region where the decay angles of the $\phi \rightarrow K^+K^-$ decay in the Gottfried Jackson frame have been determined.

Fig. 2 K^+K^- invariant mass distribution for 93 GeV incident π^- (a), K^- (b), $\bar{p}$ (c), π^+ (d), K^+ (e), p (f) and for 63 GeV incident π^- (g), K^- (h), $\bar{p}$ (i). The curves in the figure represent the results of a fit using a Breit-Wigner for the ϕ -meson and a smooth polynomial background.

Fig. 3 Decay angles of the $\phi \rightarrow K^+K^-$ decay in the Gottfried Jackson frame for inclusive ϕ events with x_F and $p_{\perp}$ values in the area indicated in fig. 1.

Fig. 4 Differential cross sections $d\sigma/dp_{\perp}^2$ for 93 GeV incident π^- (a), K^- (b), $\bar{p}$ (c), π^+ (d), K^+ (e), p (f) and 63 GeV incident π^- (g), K^- (h), $\bar{p}$ (i). The lines represent best fits to the data points with an exponential $e^{-\alpha p_{\perp}^2}$. The corresponding slope parameters α are indicated.

Fig. 5 Differential cross section $d\sigma/dx_F$ for 93 GeV incident π^- (a), K^- (b), $\bar{p}$ (c), π^+ (d), K^+ (e), p (f) and 63 GeV incident π^- (g), K^- (h), $\bar{p}$ (i). The lines correspond to the parton model predictions described in the text.

Fig. 6 Parton diagrams for ϕ -meson production

- (a) OZI allowed strange quark fusion,
- (b) OZI inhibited light quark fusion,
- (c) gluon fusion

Fig.1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 5

Fig. 6